

John E. McMurry • Robert C. Fay

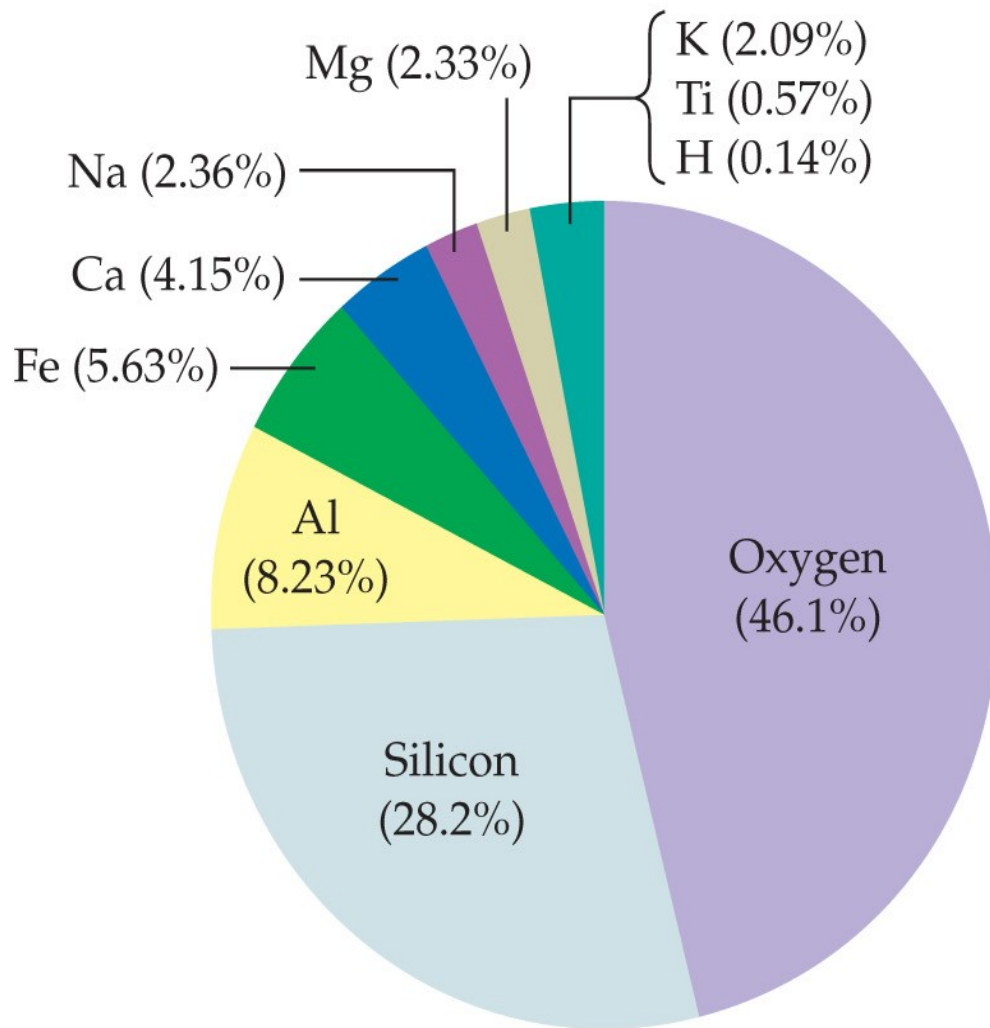
General Chemistry: Atoms First

Chapter 19 The Main-Group Elements

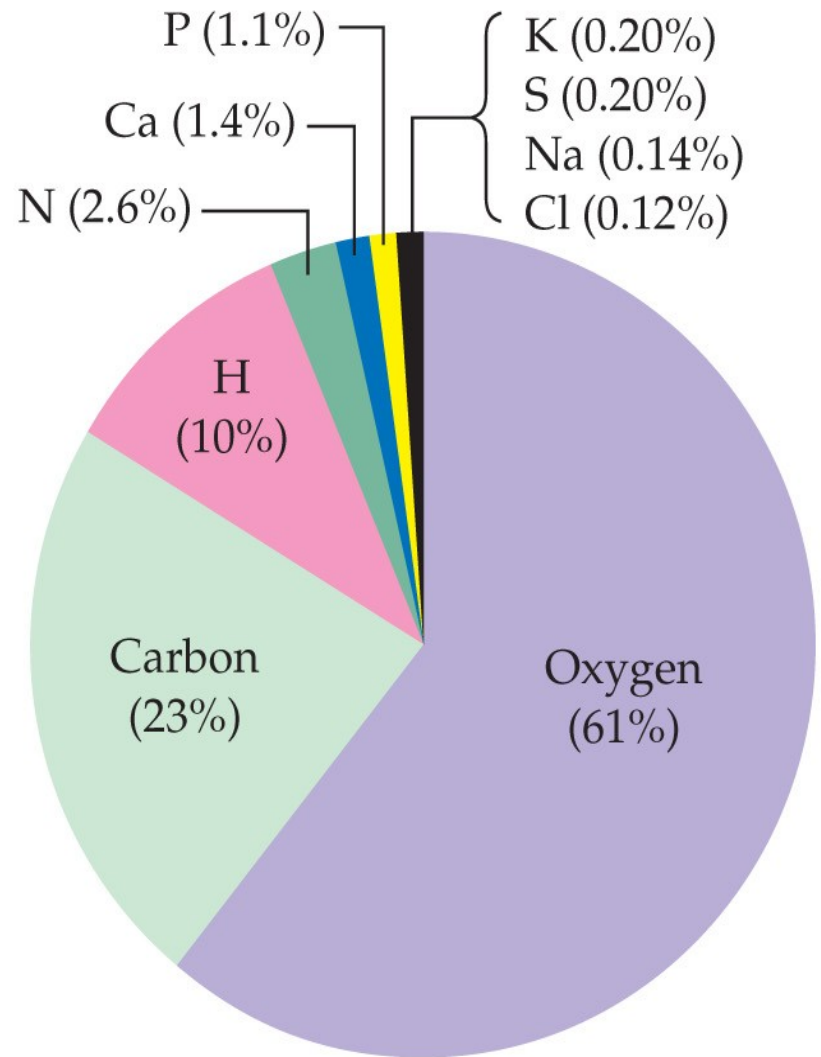
Lecture Notes

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Earth's crust



Human body

A Review of General Properties and Periodic

TABLE 19.1 The Top 10 Chemicals (2006 U.S. Production)*

Chemical	Millions of Tons	Principal Uses
Sulfuric acid (H_2SO_4)	39.6	Fertilizers, chemicals, oil refining
Nitrogen (N_2)	36.7	Inert atmospheres, low temperatures
Oxygen (O_2)	32.3	Steelmaking, welding, medical uses
Ethylene ($\text{CH}_2=\text{CH}_2$)	27.6	Plastics, antifreeze
Lime (CaO)	23.5	Steelmaking, chemicals, water treatment
Propylene ($\text{CH}_3\text{CH}=\text{CH}_2$)	17.2	Plastics, fibers, solvents
Phosphoric acid (H_3PO_4)	11.8	Fertilizers, detergents
Ammonia (NH_3)	11.4	Fertilizers, nitric acid
Chlorine (Cl_2)	11.3	Chemicals, plastics, water treatment
Ethylene dichloride ($\text{ClCH}_2\text{CH}_2\text{Cl}$)	10.7	Plastics, insecticides, solvent

*2004 data for N_2 and O_2 .

A Review of General Properties and Periodic Trends

Z_{eff} , ionization energy, electronegativity, and nonmetallic character increase

Atomic radius and metallic character decrease

Ionization energy, electronegativity, and nonmetallic character decrease

Atomic radius and metallic character increase

1 1A	2 2A						18 8A
H							He
Li	Be	13 3A	14 4A	15 5A	16 6A	17 7A	Ne
Na	Mg	Al	Si	P	S	Cl	Ar
K	Ca	Ga	Ge	As	Se	Br	Kr
Rb	Sr	In	Sn	Sb	Te	I	Xe
Cs	Ba	Tl	Pb	Bi	Po	At	Rn
Fr	Ra		114		116		

- = Metals
- = Semimetals
- = Nonmetals

Stairstep line that separates metals from nonmetals

A Review of General Properties and Periodic

TABLE 19.2 Properties of Metallic and Nonmetallic Elements

Metals	Nonmetals
All are solids at 25 °C except Hg, which is a liquid.	Eleven are gases at 25 °C, one is a liquid (Br), and five are solids (C, P, S, Se, and I).
Most have a silvery shine.	Most lack a metallic luster.
Malleable and ductile.	Nonmalleable and brittle.
Good conductors of heat and electricity.	Poor conductors of heat and electricity, except graphite.
Relatively low ionization energies.	Relatively high ionization energies.
Relatively low electronegativities.	Relatively high electronegativities.
Lose electrons to form cations.	Gain electrons to form anions; share electrons to form oxoanions.
Hydrides are ionic (or interstitial).	Hydrides are covalent and molecular.
Oxides are ionic and basic.	Oxides are covalent, molecular, and acidic.

Distinctive Properties of the Second-Row Elements

1A	2	13	14	15	16	17	8A
H	2A	3A	4A	5A	6A	7A	He
Li	Be	B	C	N	O	F	Ne
Na	Mg	Al	Si	P	S	Cl	Ar
K	Ca	Ga	Ge	As	Se	Br	Kr
Rb	Sr	In	Sn	Sb	Te	I	Xe
Cs	Ba	Tl	Pb	Bi	Po	At	Rn
Fr	Ra		114		116		

 = Metals

 = Semimetals

 = Nonmetals

Stairstep line that separates metals from nonmetals

Distinctive Properties of the Second-Row Elements

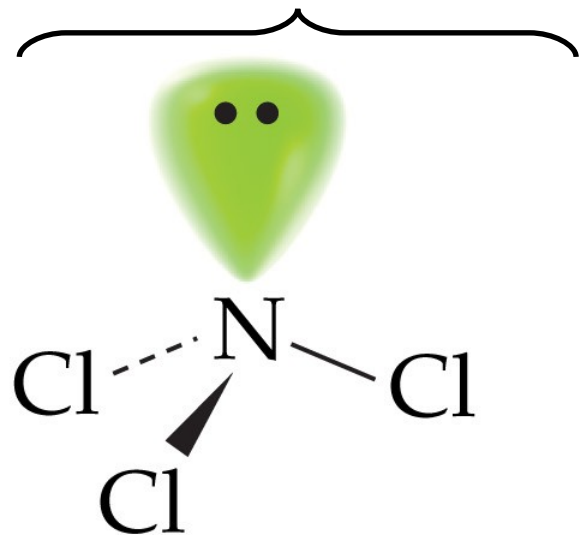
- Their small size and high electronegativity accentuate their nonmetallic behavior.
- Hydrogen bonding (typically N, O, and F).
- Out of HF, HCl, HBr, and HI, HF is the only weak hydrohalic acid.

Distinctive Properties of the Second-Row Elements

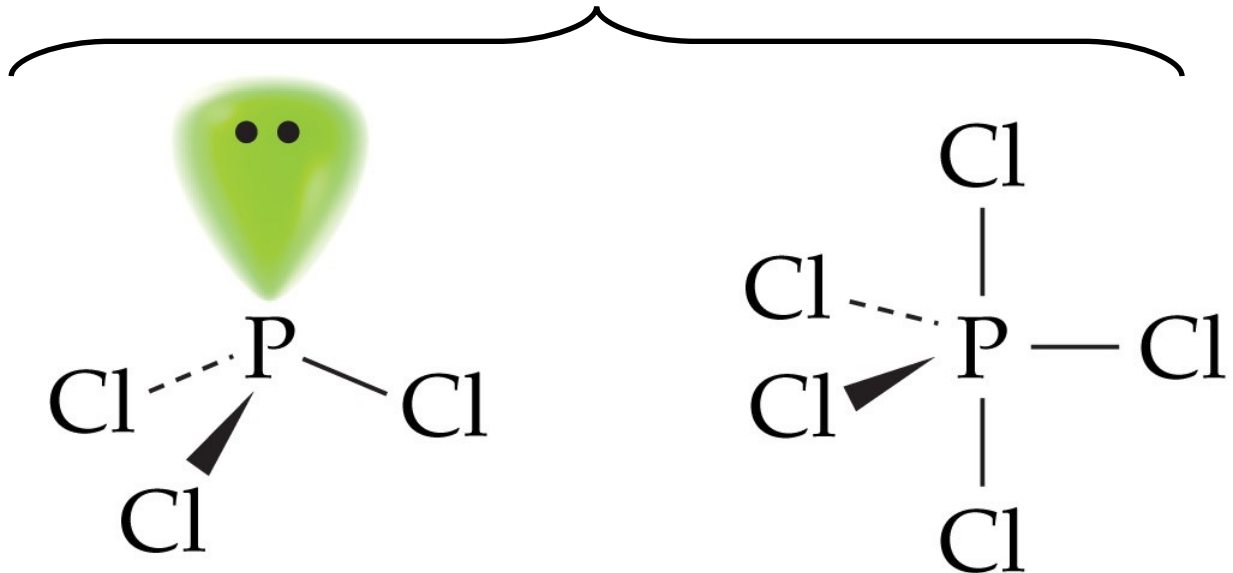
- They generally form a maximum of four covalent bonds.

Group 5a

Row 2



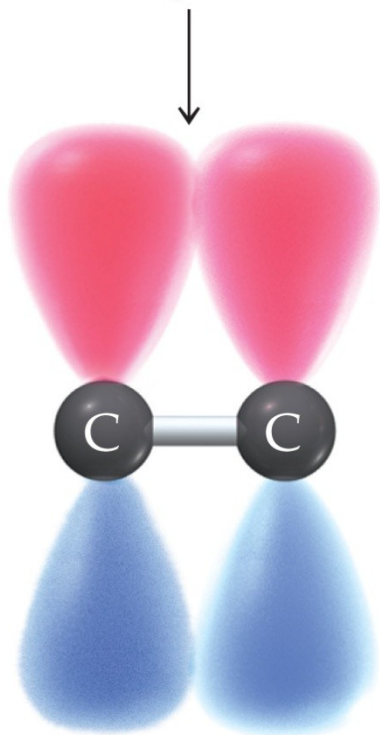
Row 3



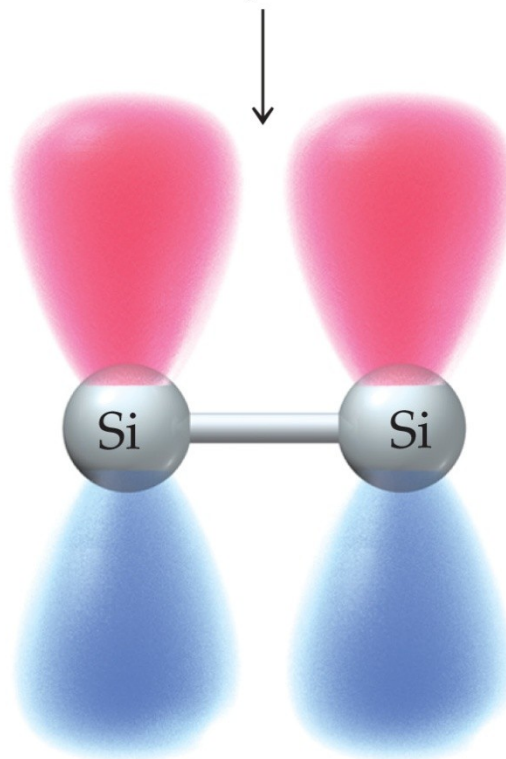
Distinctive Properties of the Second-Row Elements

- C, N, and O form multiple bonds by pi overlap of their $2p$ orbitals.

Good overlap: Multiple bonds readily form

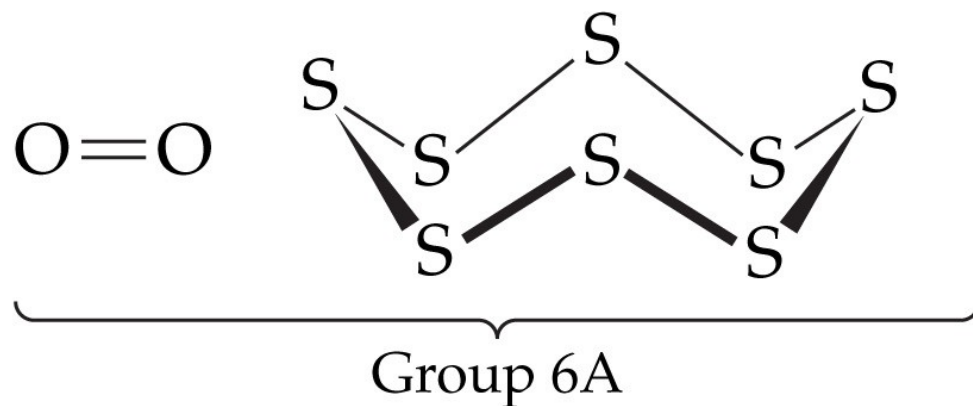
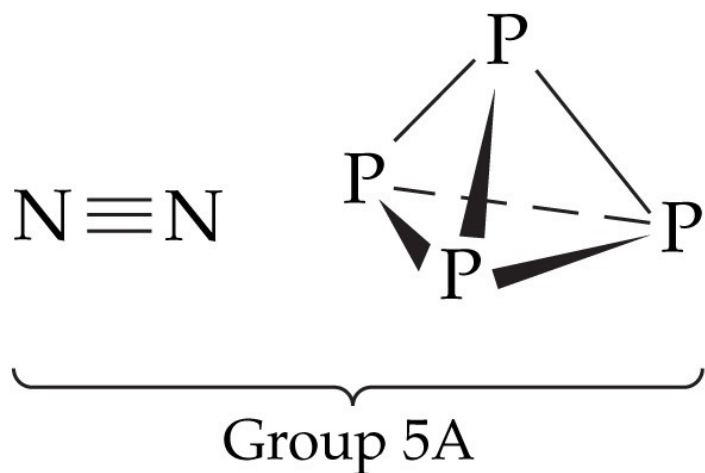


Poor overlap: Multiple bonds rarely form



Distinctive Properties of the Second-Row Elements

- C, N, and O form multiple bonds by pi overlap of their $2p$ orbitals.



The Group 3A Elements

1A	2A	13 3A	14 4A	15 5A	16 6A	17 7A	8A
H		B	C	N	O	F	He
Li	Be	Al	Si	P	S	Cl	Ne
Na	Mg	Ga	Ge	As	Se	Br	Kr
K	Ca	In	Sn	Sb	Te	I	Xe
Rb	Sr	Tl	Pb	Bi	Po	At	Rn
Cs	Ba		114		116		
Fr	Ra						

= Metals
 = Semimetals
 = Nonmetals

Stairstep line that separates metals from nonmetals

The Group 3A Elements

- Valence electron configuration is $ns^2 np^1$.
- Primary oxidation state is +3. The heavier ones also exhibit a +1 state.

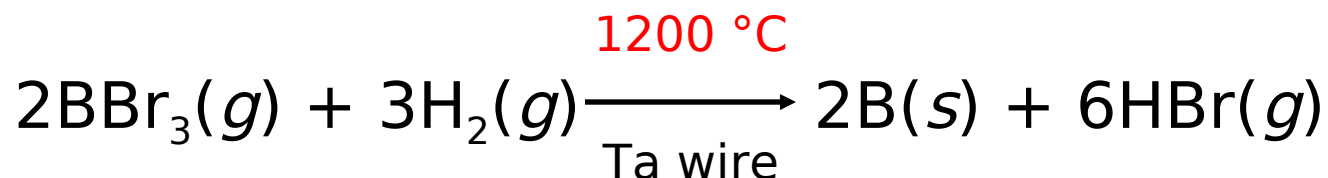
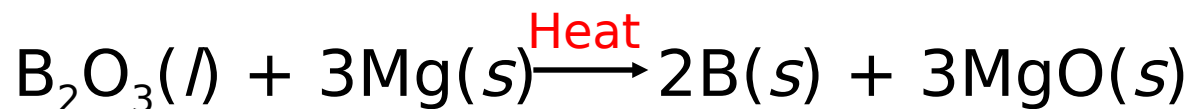
TABLE 19.3 Properties of the Group 3A Elements

Property	Boron	Aluminum	Gallium	Indium	Thallium
Valence electron configuration	$2s^2 2p^1$	$3s^2 3p^1$	$4s^2 4p^1$	$5s^2 5p^1$	$6s^2 6p^1$
Melting point (°C)	2075	660	29.8	157	304
Boiling point (°C)	4000	2519	2204	2072	1473
Density (g/cm ³)	2.34	2.70	5.91	7.31	11.8
Abundance in Earth's crust (mass %)	0.0010	8.23	0.0019	0.0002	0.00008
Common oxidation states	+3	+3	+3	+3	+3, +1
Atomic radius (pm)	83	143	135	167	170
M ³⁺ ionic radius (pm)		54	62	80	89
First ionization energy (kJ/mol)	801	578	579	558	589
Electronegativity	2.0	1.5	1.6	1.7	1.8
Redox potential, E° (V) for $M^{3+}(aq) + 3 e^- \rightarrow M(s)$	-0.87*	-1.66	-0.55	-0.34	-0.34 [†]

* E° for the reaction $B(OH)_3(aq) + 3 H^+(aq) + 3 e^- \rightarrow B(s) + 3 H_2O(l)$

[†] E° for the reaction $Tl^+(aq) + e^- \rightarrow Tl(s)$

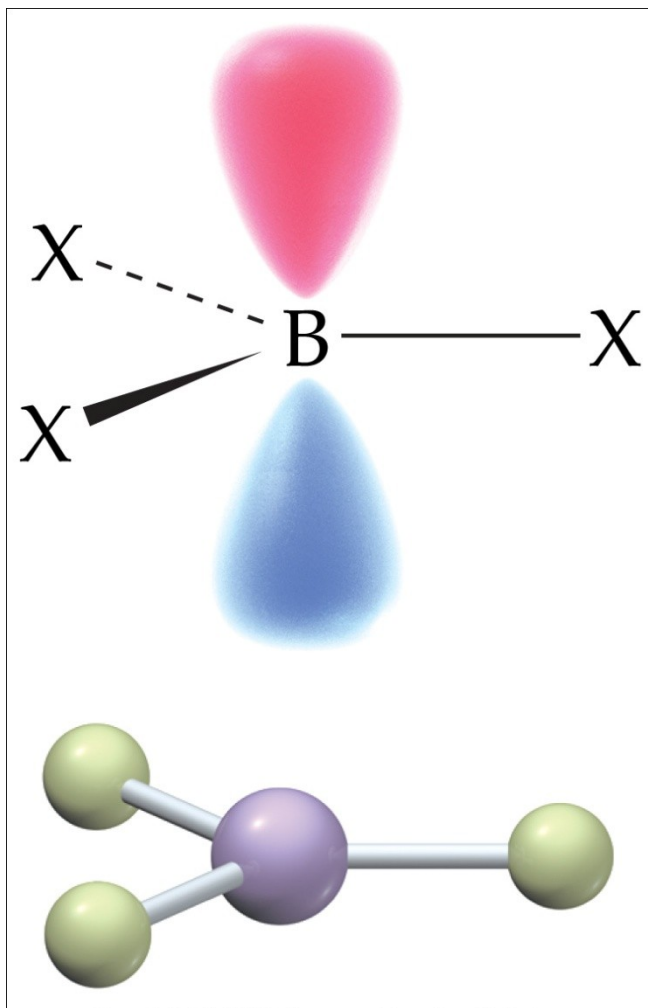
Boron



- Strong and hard substance.
- High-melting point (2075 °C).
- Chemically inert at room temperature except with fluorine.

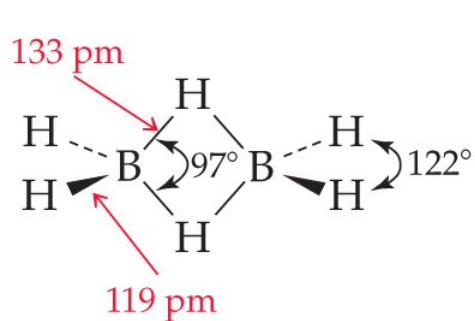
Boron

Boron halides are highly reactive, volatile, covalent compounds.

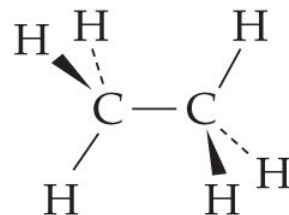
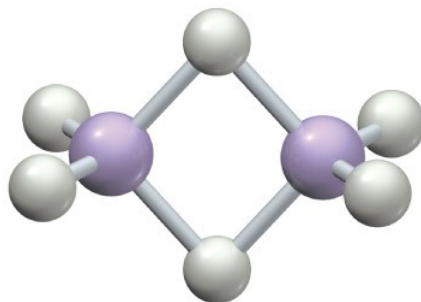


Boron

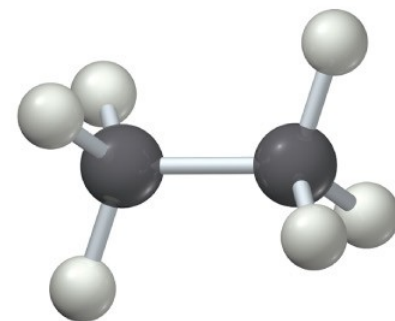
- Boron hydrides, or **boranes**, are volatile, molecular compounds with formulas B_nH_m .



Diborane



Ethane



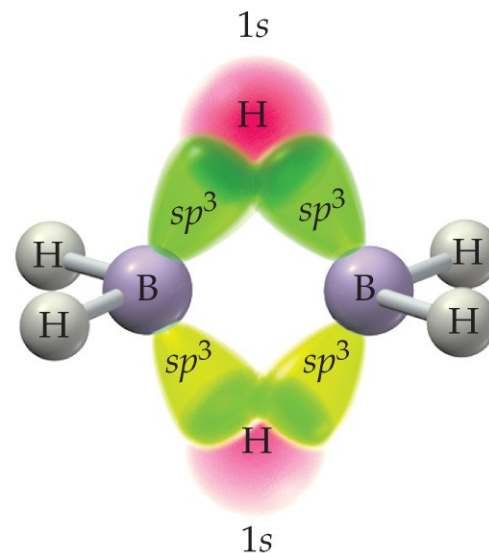
Boron

- Boron hydrides, or **boranes**, are volatile, molecular compounds with

formulas B_nH_m .

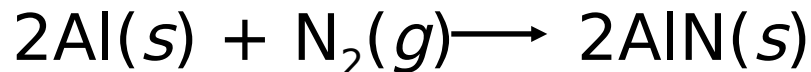
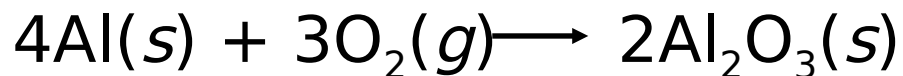
- Diborane is *electron-deficient*. The bridging H atom is bonded to *both* B atoms and forms a *three-center, two-electron* bond (3c-2e bond).

Each of the two MOs (one shown darker than the other) is formed by the interaction of an sp^3 hybrid orbital on each B atom and the 1s orbital on one bridging H atom.

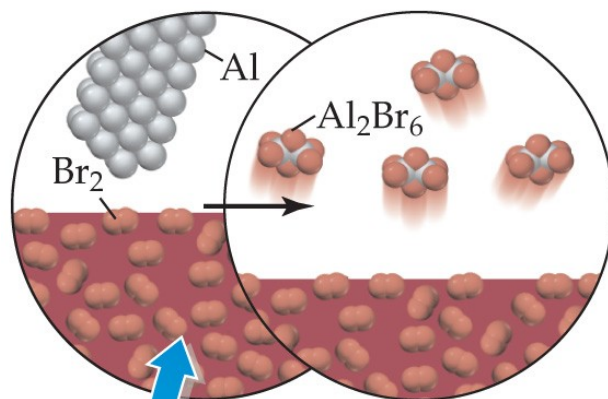


Each MO contains one pair of electrons and accounts for the bonding in one B–H–B bridge.

Aluminum

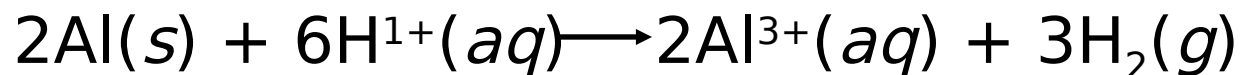


Aluminum

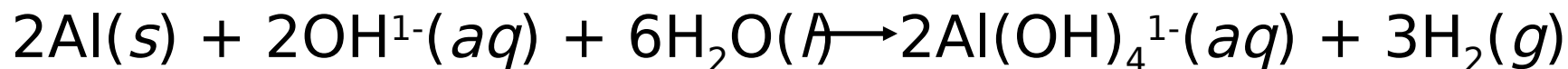


Aluminum

Acidic solution:



Basic solution:



The Group 4A Elements

1A							8A	
H	2		13	14	15	16	17	He
	2A		3A	4A	5A	6A	7A	
Li	Be	B	C	N	O	F	Ne	
Na	Mg	Al	Si	P	S	Cl	Ar	
K	Ca	Ga	Ge	As	Se	Br	Kr	
Rb	Sr	In	Sn	Sb	Te	I	Xe	
Cs	Ba	Tl	Pb	Bi	Po	At	Rn	
Fr	Ra		114		116			

= Metals

= Semimetals

= Nonmetals

Stairstep line that separates metals from nonmetals

The Group 4A Elements

- Valence electron configuration is $ns^2 np^2$.
- The group 4a elements exemplify the increase in metallic character down a group in the periodic table.

TABLE 19.4 Properties of the Group 4A Elements

Property	Carbon	Silicon	Germanium	Tin	Lead
Valence electron configuration	$2s^2 2p^2$	$3s^2 3p^2$	$4s^2 4p^2$	$5s^2 5p^2$	$6s^2 6p^2$
Melting point (°C)	>3550*	1414	938	232 [†]	327
Boiling point (°C)		3265	2833	2602	1749
Density (g/cm ³)	3.51*	2.33	5.32	7.29 [†]	11.3
Abundance in Earth's crust (mass %)	0.020	28.2	0.0005	0.0002	0.0013
Common oxidation states	+2, +4	+4	+4	+2, +4	+2, +4
Atomic radius (pm)	77	118	122	140	175
First ionization energy (kJ/mol)	1086	787	762	709	716
Electronegativity	2.5	1.8	1.8	1.8	1.9
Redox potential, E° (V) for $M^{2+}(aq) + 2e^- \rightarrow M(s)$				-0.14	-0.13

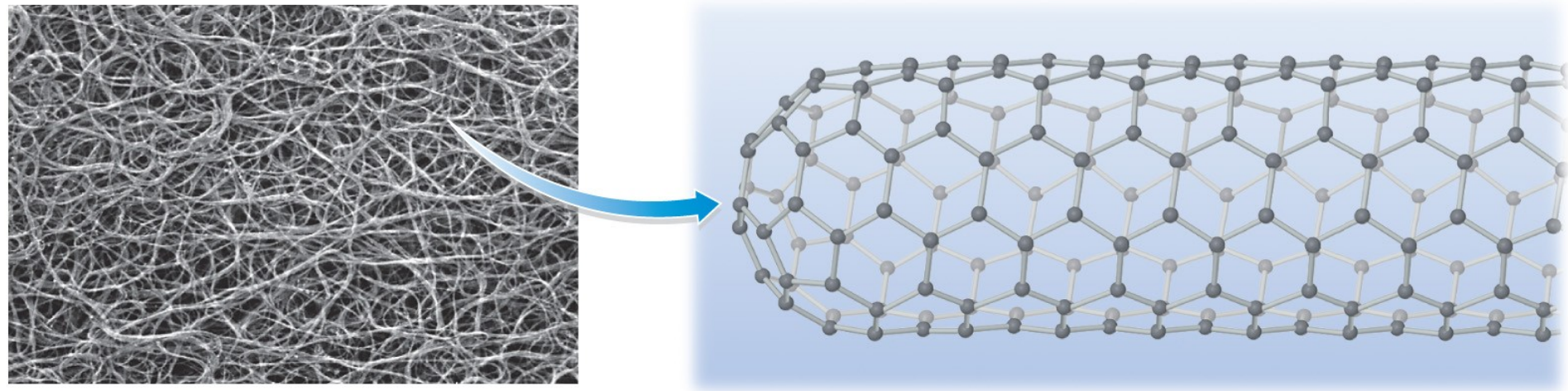
*Diamond

† White Sn

Carbon

- Second most abundant element in living organisms.
- Multiple allotropes (diamond, graphite, fullerene, and nanotubes).
- Present in carbonate minerals and fossil fuels.

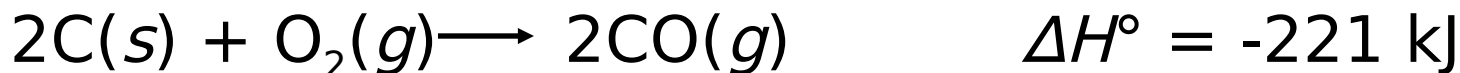
Carbon



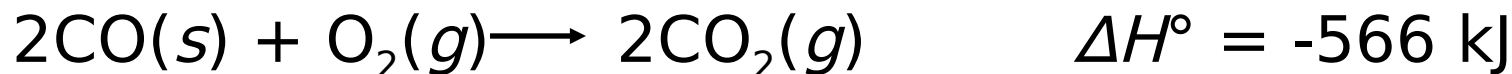
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Carbon

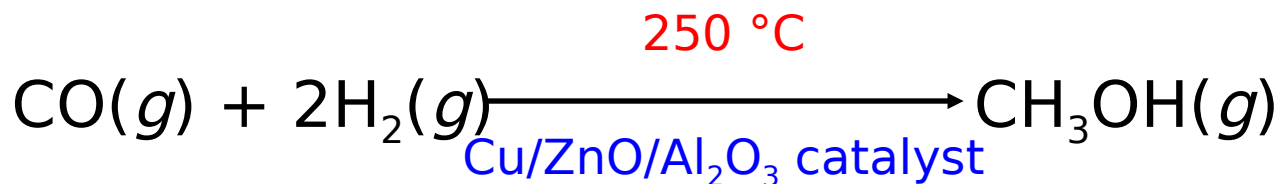
Oxides of Carbon



- In excess oxygen, CO is oxidized to CO_2 :



- The production of methanol is one of the main industrial uses of CO:



Carbon

Oxides of Carbon

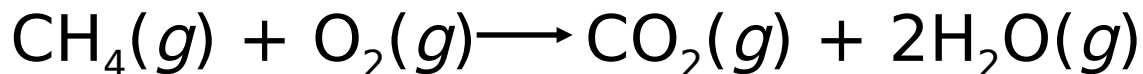
Oxyhemoglobin



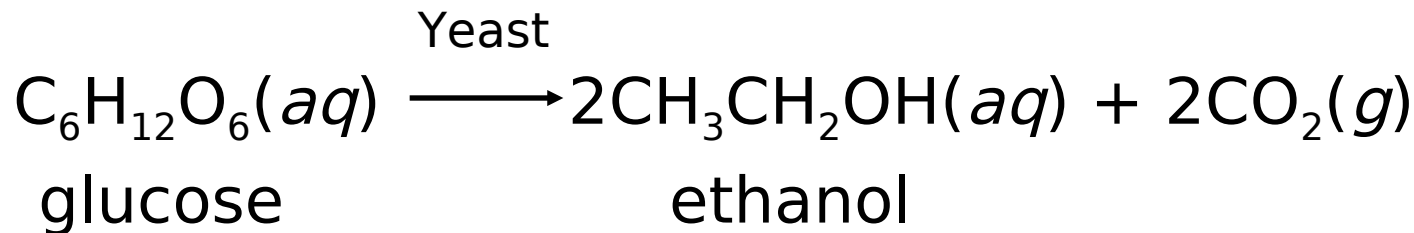
Carboxyhemoglobin

Carbon

CO₂ Production



- Industrially, CO₂ is produced by the yeast-catalyzed fermentation of sugar in the manufacture of alcoholic drinks:



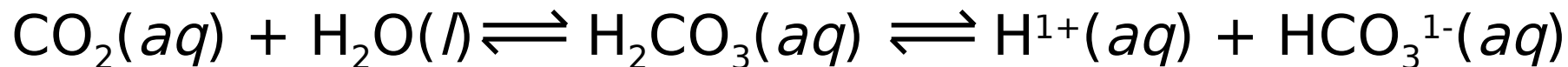
Carbon

CO₂ Production

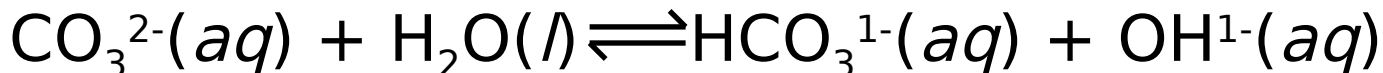
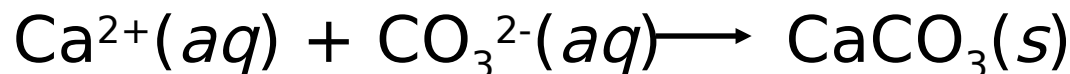


Carbon***

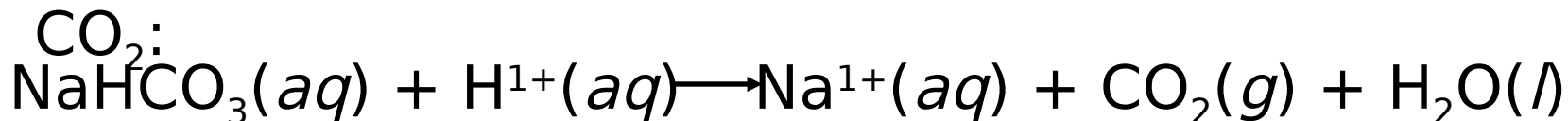
Carbonates



- Washing soda, $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$, is used to launder textiles:



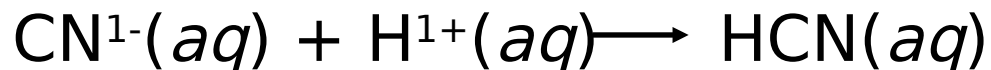
- Baking soda, NaHCO_3 , reacts with acids to yield



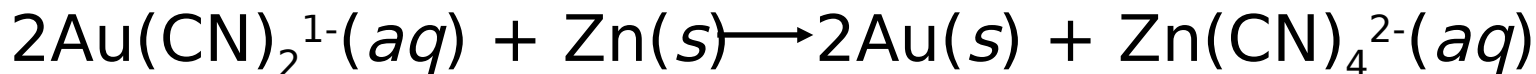
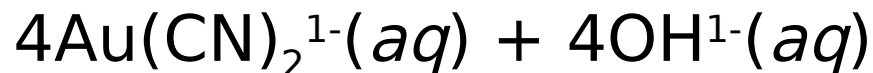
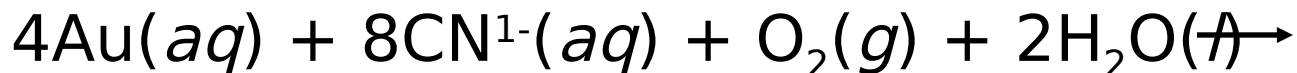
Carbon

Hydrogen Cyanide and Cyanides

- HCN is **very** toxic and is produced when metal cyanides are acidified:



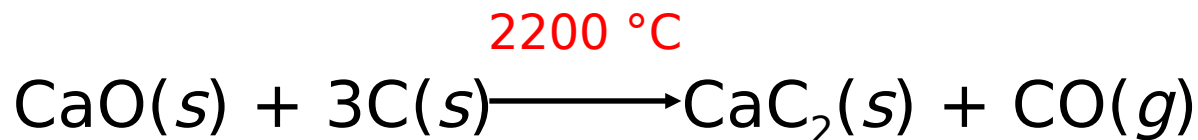
- Cyanide is a *pseudohalide ion* because it behaves like chloride ion:



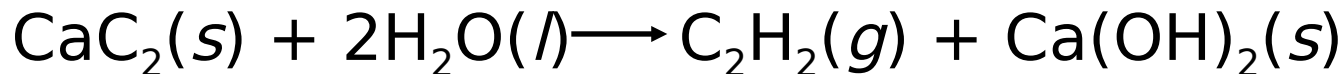
Carbon

Carbides

- A binary inorganic compound in which carbon has a negative oxidation state:

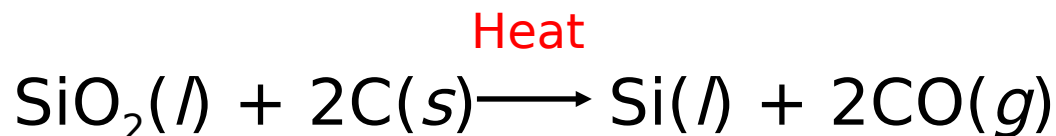


- Calcium carbide is used to prepare acetylene, C_2H_2 , for oxyacetylene welding:



Silicon

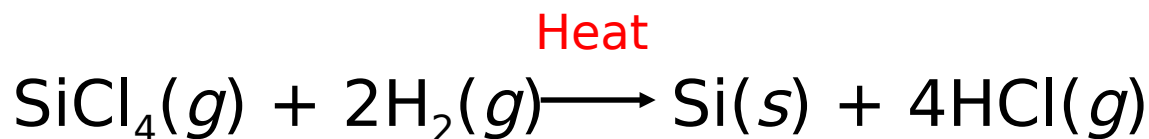
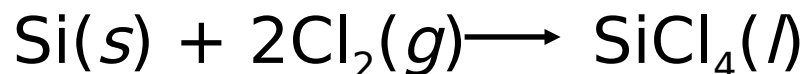
- Silica (SiO_2 , sand) is reacted with coke in an electric furnace:



- Hard, gray semiconducting solid.
- Melts at 1414 °C.

Silicon

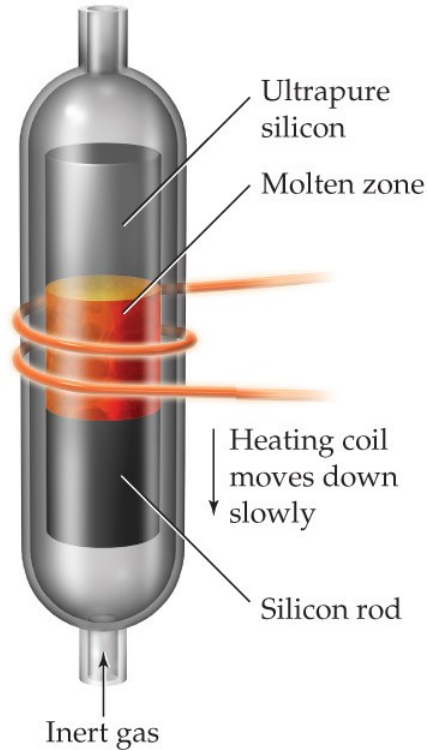
- To purify the silicon for ultrapure applications (semiconductors):



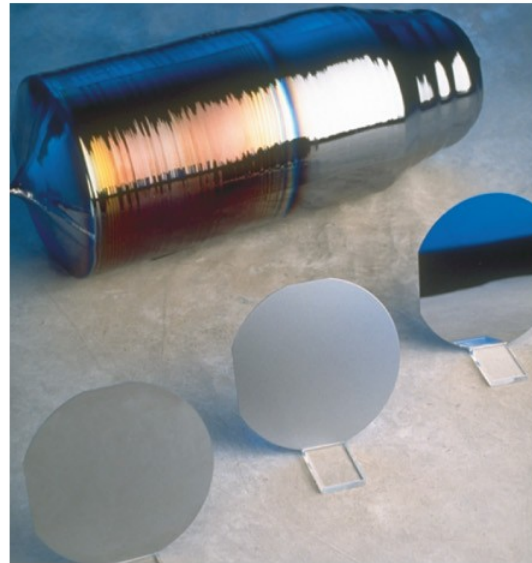
- Purified further by a process called *zone refining*.

Silicon

The heater coil sweeps the molten zone and the impurities to the lower end of the rod. After the rod has cooled, the impurities are removed by cutting off the rod's lower end.



(a)

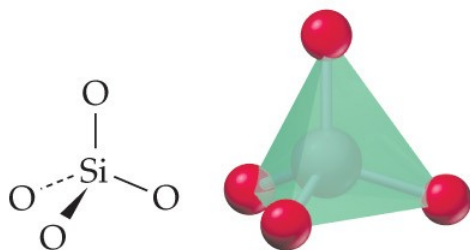


(b)

Silicon wafers are used to produce the integrated-circuit chips found in solid-state electronic devices.

Silicon

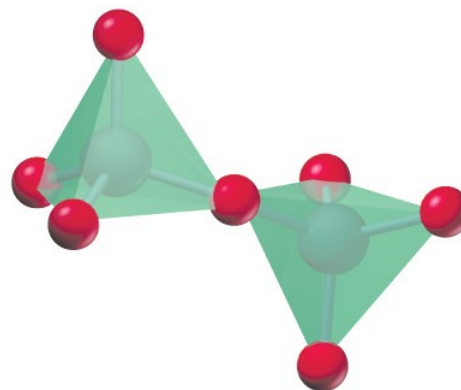
Silicates



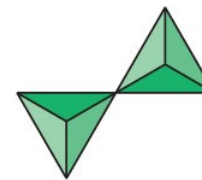
A view of the SiO_4^{4-} anion showing the tetrahedral SiO_4 structural unit.



A tetrahedron is used as a shorthand representation of the SiO_4^{4-} anion. An O atom is located at each corner of the tetrahedron, and the Si atom is at the center.



A view of the $\text{Si}_2\text{O}_7^{6-}$ anion.



A shorthand representation of the $\text{Si}_2\text{O}_7^{6-}$ anion. The corner shared by the two tetrahedra represents a shared O atom.

Silicon

Silicates



Silicon

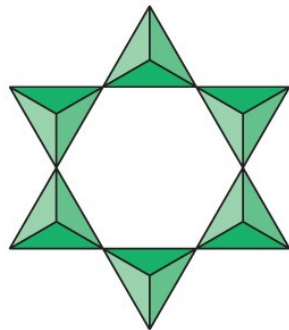
Silicates



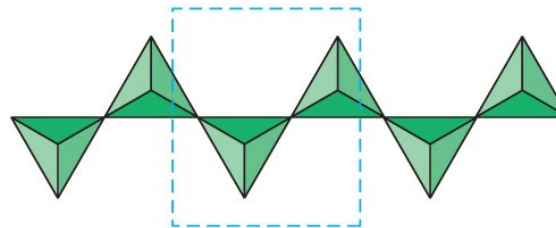
(a) Emerald, a green beryl ($\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$) with about 2% Cr^{3+} ions substituting for Al^{3+}



(b) Diopside ($\text{CaMgSi}_2\text{O}_6$)



(c) The cyclic anion $\text{Si}_6\text{O}_{18}^{12-}$ in beryl



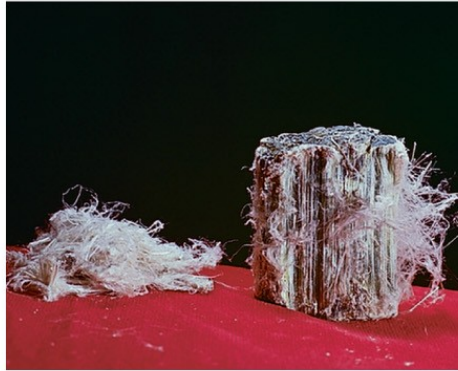
Repeating unit, $\text{Si}_2\text{O}_6^{4-}$

(d) The infinitely extended chain anion $(\text{Si}_2\text{O}_6^{4-})_n$ in diopside

The number of negative charges on the $\text{Si}_2\text{O}_6^{4-}$ repeating unit equals the number of terminal (unshared) O atoms in that unit (four).

Silicon

Silicates

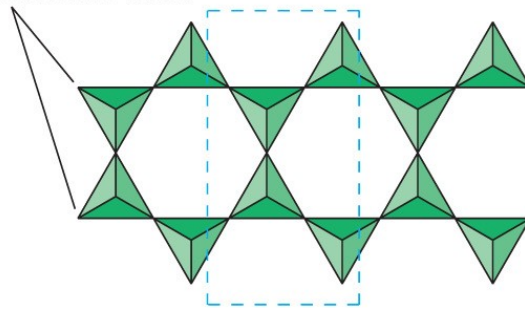


(a) Asbestos is a fibrous material because of its chain structure.



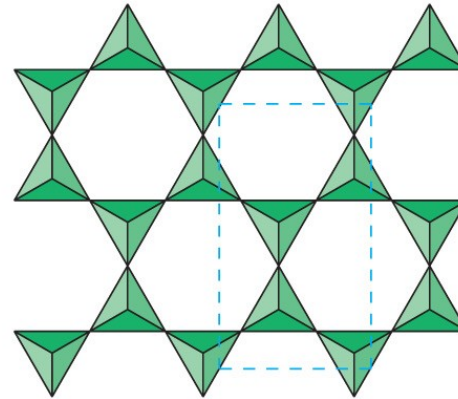
(b) Mica cleaves into thin sheets because of its two-dimensional layer structure.

Two of the single-stranded chains of Figure 19.6d are laid side by side, and half of the SiO_4 tetrahedra share an additional O atom.



Repeating unit, $\text{Si}_4\text{O}_{11}^{6-}$

(c) The double-stranded chain anion $(\text{Si}_4\text{O}_{11}^{6-})_n$ in asbestos minerals

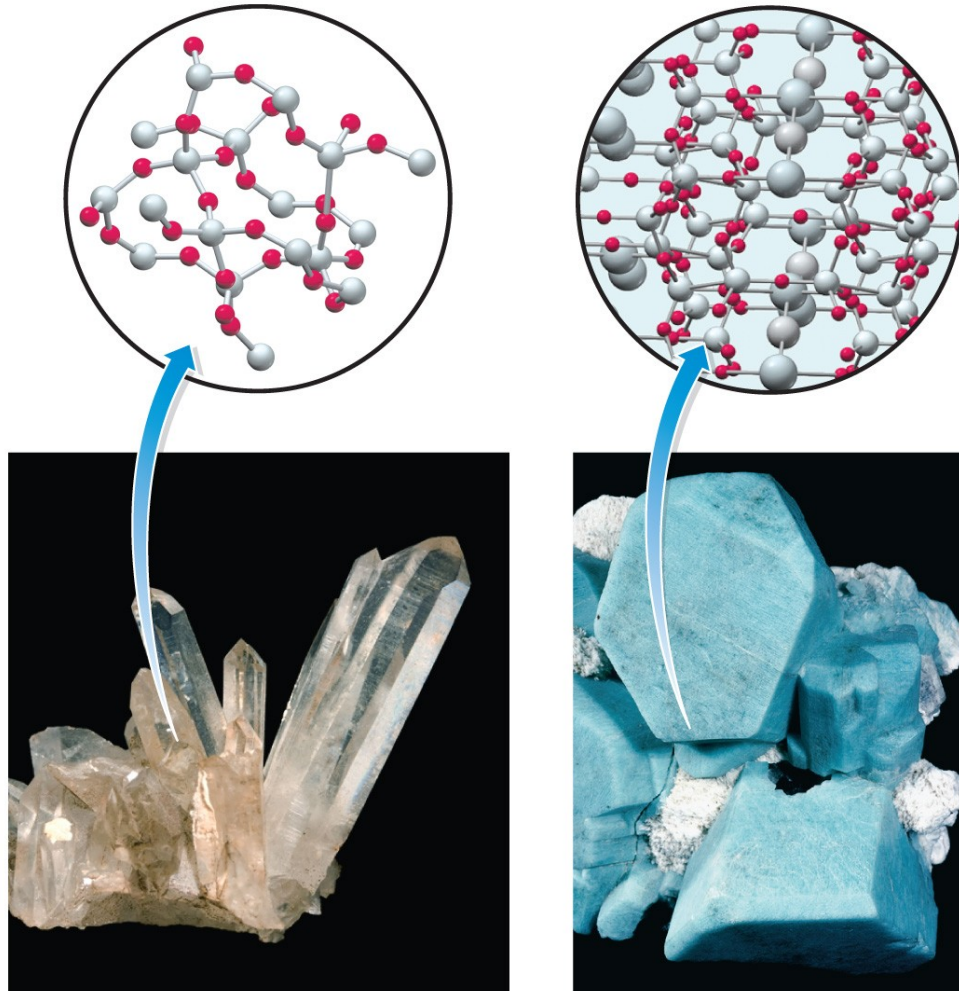


Repeating unit, $\text{Si}_4\text{O}_{10}^{4-}$

(d) The layer anion $(\text{Si}_4\text{O}_{10}^{4-})_n$ in mica is formed by the sharing of three O atoms per SiO_4 tetrahedron.

The number of negative charges on each repeating unit equals the number of terminal O atoms in that unit.

Silicon



(a) Quartz

(b) Orthoclase

Germanium, Tin, and Lead

1A							8A	
H	2 2A		13 3A	14 4A	15 5A	16 6A	17 7A	He
Li	Be		B	C	N	O	F	Ne
Na	Mg		Al	Si	P	S	Cl	Ar
K	Ca		Ga	Ge	As	Se	Br	Kr
Rb	Sr		In	Sn	Sb	Te	I	Xe
Cs	Ba		Tl	Pb	Bi	Po	At	Rn
Fr	Ra			114		116		

= Metals

= Semimetals

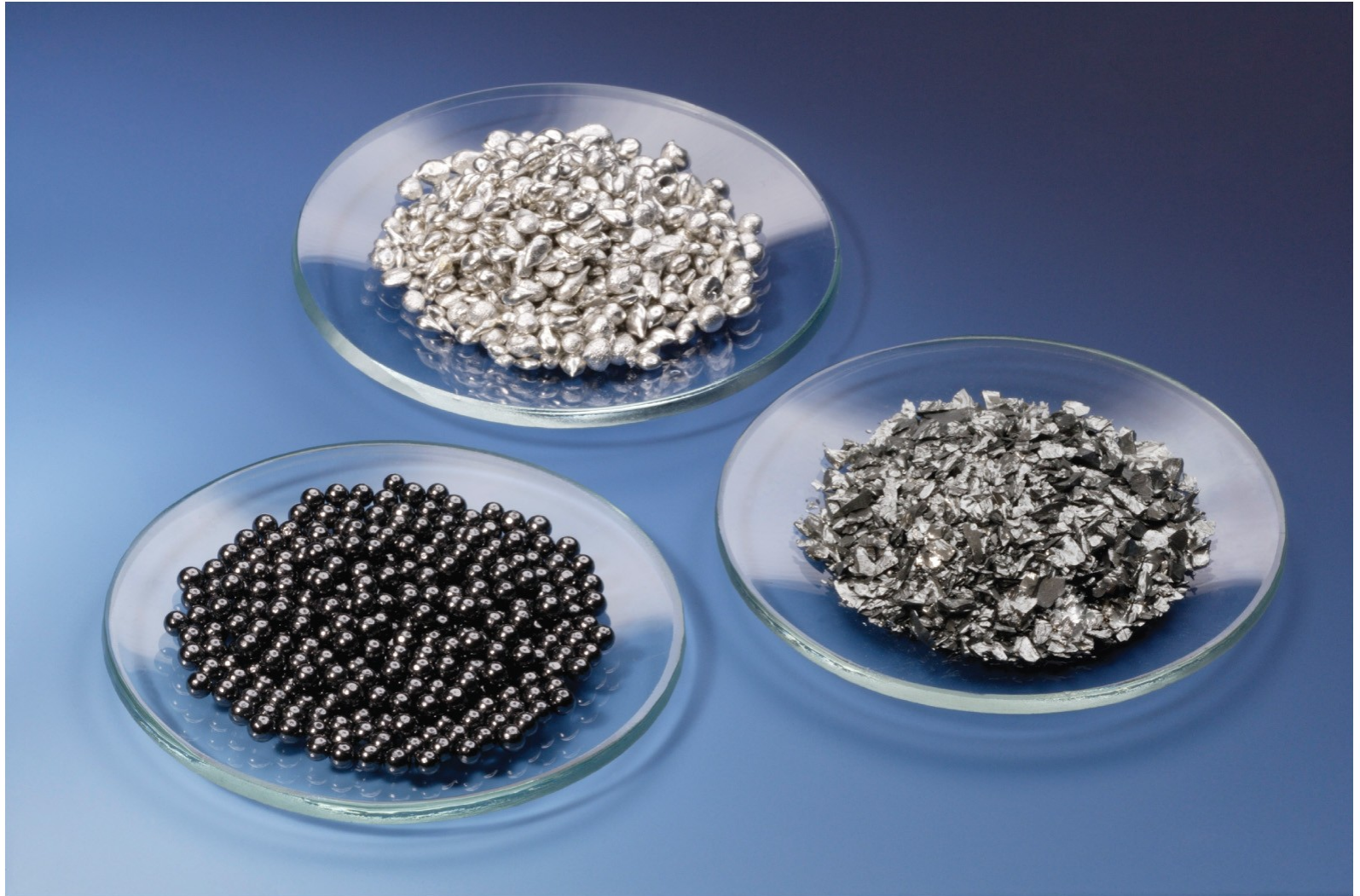
= Nonmetals

Stairstep line that separates metals from nonmetals

Germanium, Tin, and Lead

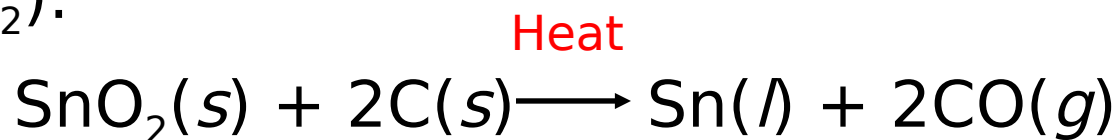
- Germanium is a relatively high-melting, brittle semiconductor with the same crystal structure as diamond and silicon.
- Tin has two allotropic forms:
 - A brittle, semiconducting form with a diamond structure called *gray tin*.
 - A silvery, low-melting, white metallic form called *white tin*.
- Lead is a soft, low-melting metal.

Germanium, Tin, and Lead

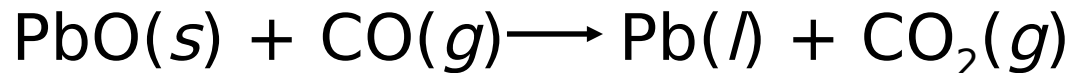
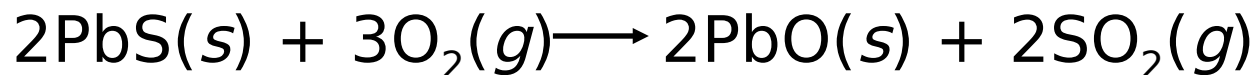


Germanium, Tin, and Lead

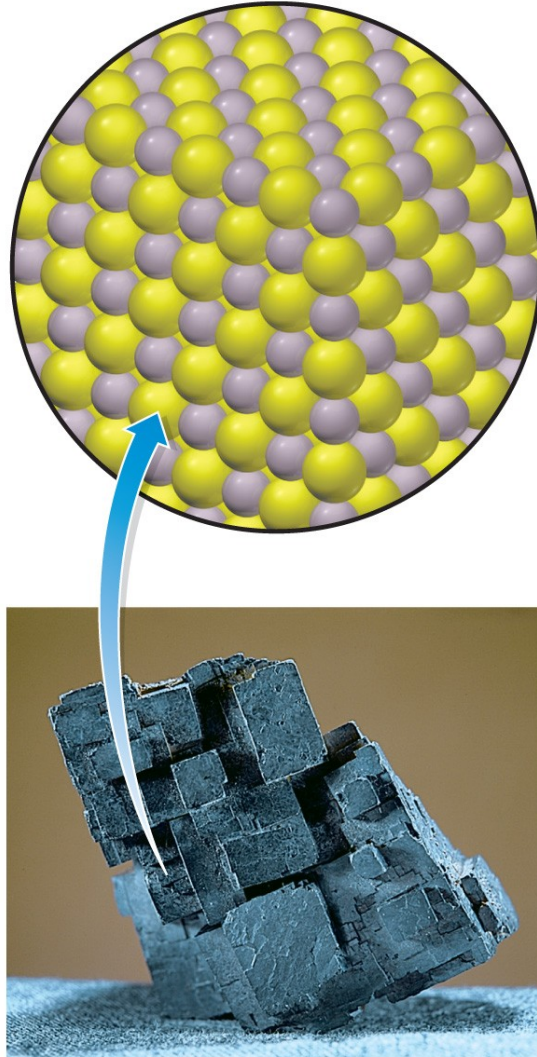
- Tin is obtained from the mineral cassiterite (SnO_2):



- Lead is obtained from the ore galena (PbS):



Germanium, Tin, and Lead



The Group 5A Elements

1A		2		13	14	15	16	17	8A
H	2A			3A	4A	5A	6A	7A	He
Li	Be			B	C	N	O	F	Ne
Na	Mg			Al	Si	P	S	Cl	Ar
K	Ca			Ga	Ge	As	Se	Br	Kr
Rb	Sr			In	Sn	Sb	Te	I	Xe
Cs	Ba			Tl	Pb	Bi	Po	At	Rn
Fr	Ra				114		116		

 = Metals
 = Semimetals
 = Nonmetals

Stairstep line that separates metals from nonmetals

The Group 5A Elements

- Valence electron configuration is $ns^2 np^3$.
- N and P are typical nonmetals, As and Sb are semimetals, and Bi is a metal.

TABLE 19.5 Properties of the Group 5A Elements

Property	Nitrogen	Phosphorus	Arsenic	Antimony	Bismuth
Valence electron configuration	$2s^2 2p^3$	$3s^2 3p^3$	$4s^2 4p^3$	$5s^2 5p^3$	$6s^2 6p^3$
Melting point (°C)	−210	44*	614 [†]	631	271
Boiling point (°C)	−196	280		1587	1564
Atomic radius (pm)	75	110	120	140	150
First ionization energy (kJ/mol)	1402	1012	944	831	703
Electronegativity	3.0	2.1	2.0	1.9	1.9

*White phosphorus

[†] Sublimes

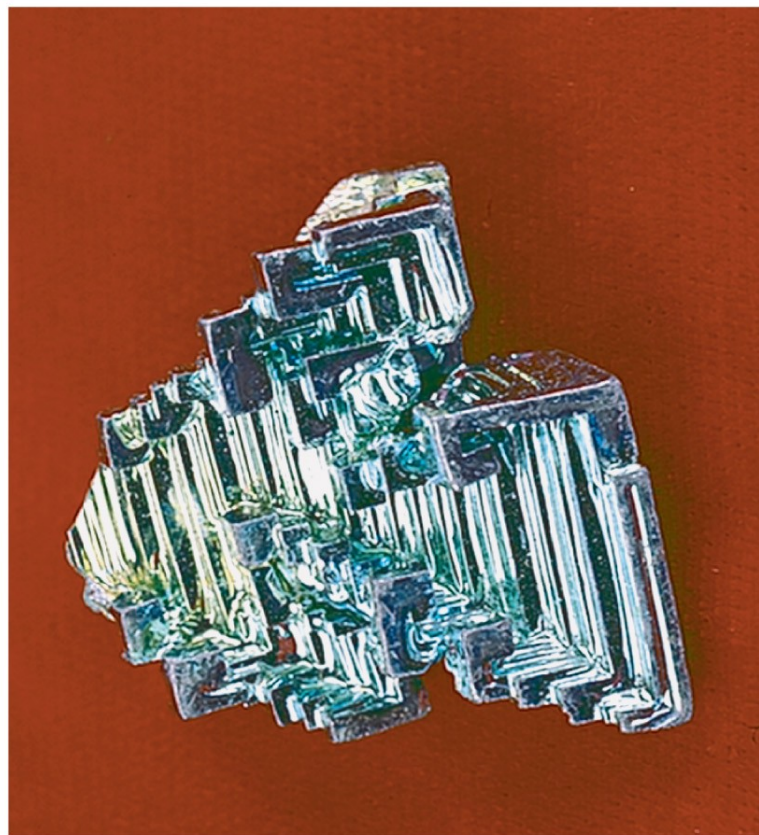
The Group 5A Elements



Arsenic



Antimony



Bismuth

Nitrogen

- Elemental nitrogen is a colorless, odorless, tasteless gas that makes up 78% of the Earth's atmosphere by volume.
- It is the most volatile component of liquid air (bp -196 °C) and is easily separated from the less volatile oxygen (bp -183 °C) and argon (bp -186 °C) by fractional distillation.
- Nitrogen will react with hydrogen to form ammonia, but requires high pressures, high temperatures, and a catalyst (Haber process):
$$\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \xrightarrow[\text{Fe/K}_2\text{O/Al}_2\text{O}_3 \text{ catalyst}]{400-500\text{ }^\circ\text{C}, 130-300\text{ atm}} 2\text{NH}_3(\text{g})$$

Nitrogen

TABLE 19.6 Oxidation States of Nitrogen and Representative Compounds

Oxidation State	Compound	Formula	Electron-Dot Structure
-3	Ammonia	NH ₃	$\begin{array}{c} \text{H}-\ddot{\text{N}}-\text{H} \\ \\ \text{H} \end{array}$
-2	Hydrazine	N ₂ H ₄	$\begin{array}{c} \text{H}-\ddot{\text{N}}-\ddot{\text{N}}-\text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array}$
-1	Hydroxylamine	NH ₂ OH	$\begin{array}{c} \text{H}-\ddot{\text{N}}-\ddot{\text{O}}-\text{H} \\ \\ \text{H} \end{array}$
+1	Nitrous oxide	N ₂ O	$:\text{N}\equiv\text{N}-\ddot{\text{O}}:$
+2	Nitric oxide	NO	$:\dot{\text{N}}=\ddot{\text{O}}:$
+3	Nitrous acid	HNO ₂	$\text{H}-\ddot{\text{O}}-\ddot{\text{N}}=\ddot{\text{O}}:$
+4	Nitrogen dioxide	NO ₂	$:\ddot{\text{O}}-\dot{\text{N}}=\ddot{\text{O}}:$
+5	Nitric acid	HNO ₃	$\begin{array}{c} \text{H}-\ddot{\text{O}}-\text{N}=\ddot{\text{O}}: \\ \\ :\ddot{\text{O}}: \end{array}$

Nitrogen

Ammonia

- Ammonia is a starting compound for the synthesis of many important nitrogen compounds.
- It is very soluble in water.
- Neutralization of aqueous ammonia with acids yields ammonium salts, which resemble alkali metal salts in their solubility.
- It is a Brønsted-Lowry base:



Nitrogen

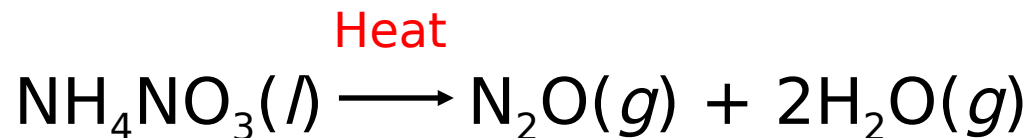
Hydrazine

- Hydrazine can be prepared by the reaction of ammonia with a basic solution of sodium hypochlorite (NaOCl):
$$2\text{NH}_3(aq) + \text{OCl}^{1-}(aq) \longrightarrow \text{N}_2\text{H}_4(aq) + \text{H}_2\text{O}(l) + \text{Cl}^{1-}(aq)$$
- Pure hydrazine is a poisonous, colorless liquid that smells like ammonia, freezes at 2°C, and boils at 114 °C.
- It is violently explosive in the presence of air or other oxidizing agents:
$$2\text{N}_2\text{H}_4(l) + \text{N}_2\text{O}_4(l) \longrightarrow 3\text{N}_2(g) + 4\text{H}_2\text{O}(g) \Delta H^\circ = -1049 \text{ kJ}$$

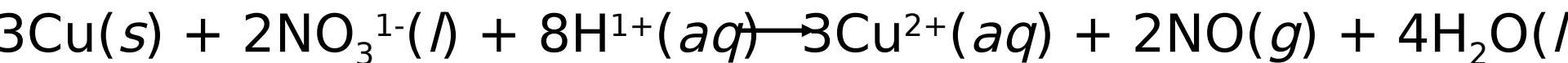
Nitrogen

Oxides of Nitrogen

- **Nitrous oxide (N₂O)** is a colorless, sweet-smelling gas obtained when molten ammonium nitrate is heated *gently* at about 270 °C:



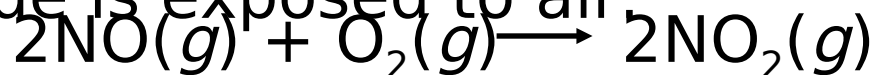
- **Nitric oxide (NO)** is a colorless gas, produced in the laboratory when copper metal is treated with *dilute* nitric acid:



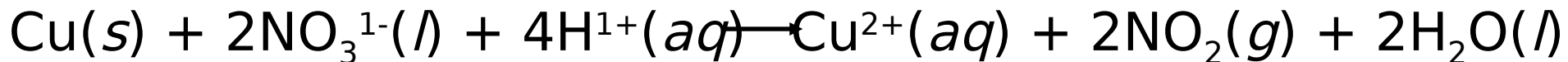
Nitrogen

Oxides of Nitrogen

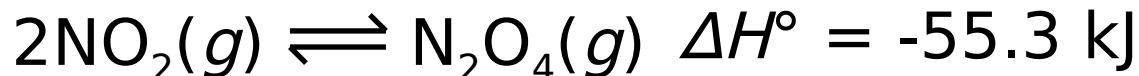
- **Nitrogen dioxide (NO₂)** is a highly toxic, reddish-brown gas that forms rapidly when nitric oxide is exposed to air:



- NO₂ can also be produced when copper reacts with *concentrated* nitric acid:



- Nitrogen dioxide tends to dimerize:



Nitrogen



Nitric oxide is a colorless gas.



NO turns brown on contact with air because it is rapidly oxidized to NO_2 .

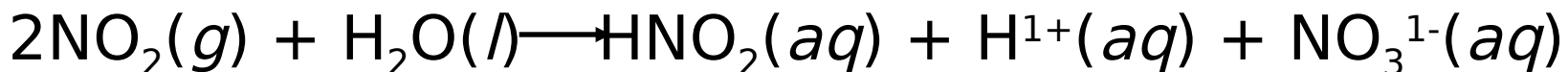


Copper reacts with concentrated HNO_3 , yielding noxious, red-brown fumes of NO_2 . The blue color of the solution is due to Cu^{2+} ions.

Nitrogen

Oxides of Nitrogen

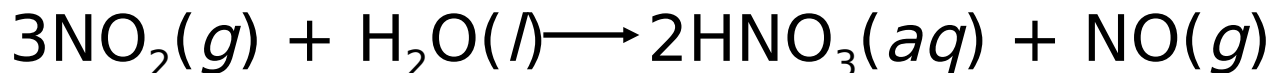
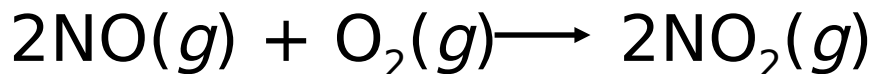
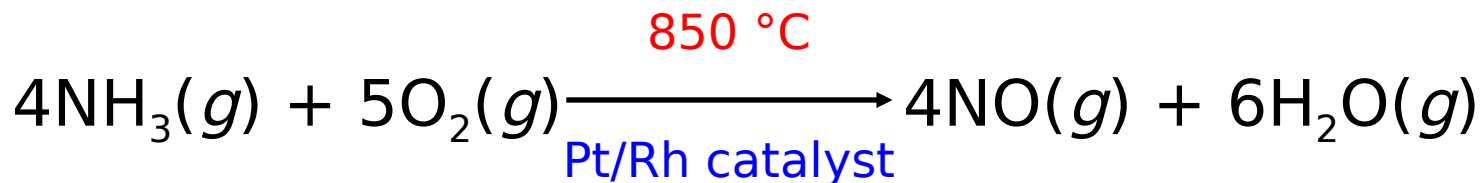
- **Nitrous acid (HNO_2)** is formed by a reaction between nitrogen dioxide and water:



Nitrogen

Oxides of Nitrogen

- **Nitric acid (HNO_3)** is produced industrially by the multistep *Ostwald process*:



Nitrogen

Oxides of Nitrogen

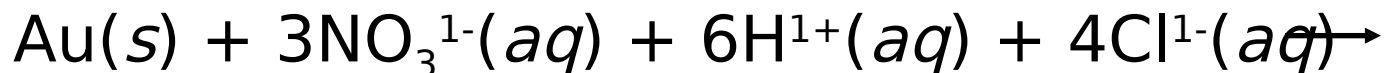
- Concentrated nitric acid often has a yellow-brown color due to the presence of a small amount of NO_2 :
$$4\text{HNO}_3(aq) \longrightarrow 4\text{NO}_2(aq) + \text{O}_2(g) + 2\text{H}_2\text{O}(l)$$



Nitrogen

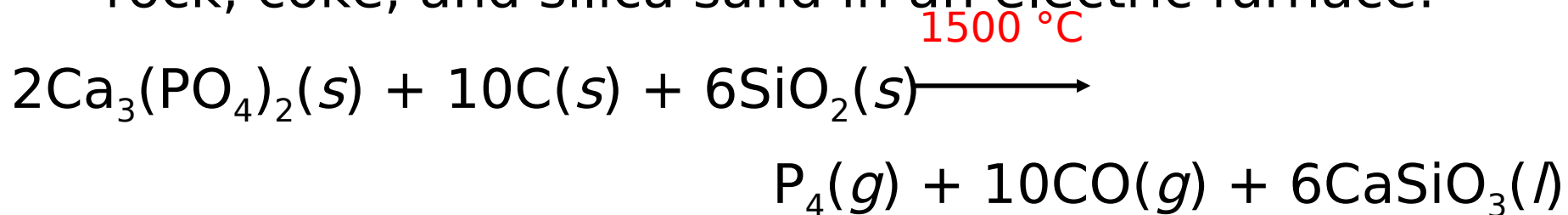
Oxides of Nitrogen

- *Aqua regia* is a mixture of concentrated HCl and concentrated HNO₃ in a 3:1 volume ratio which will oxidize even inactive metals like gold:



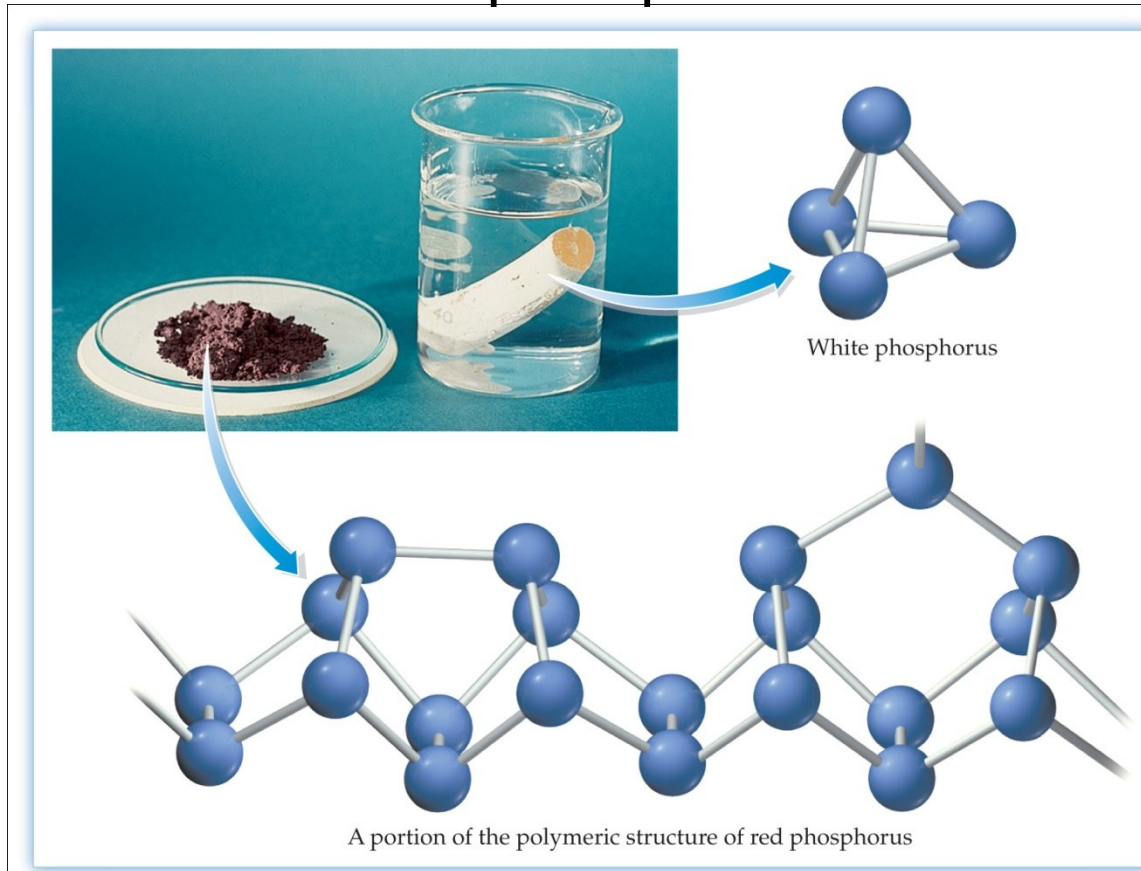
Phosphorus

- Phosphorus is the most abundant element of group 5a. It is obtained by reacting phosphate rock, coke, and silica sand in an electric furnace:



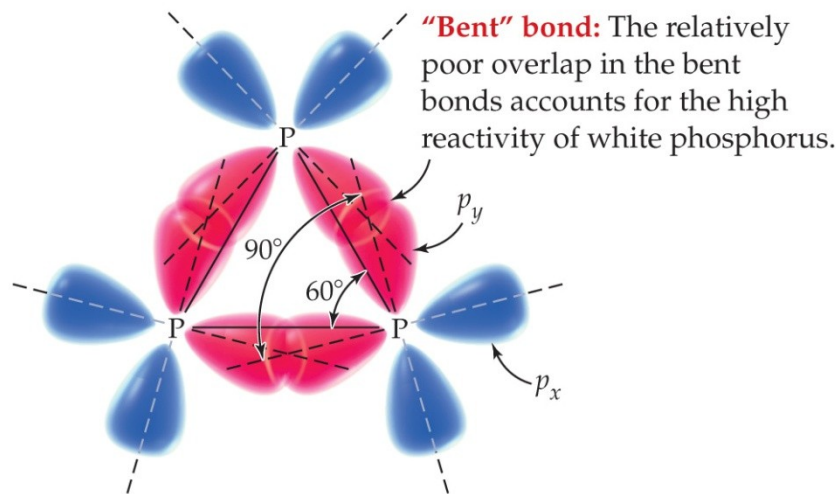
Phosphorus

- The element exists in two allotropes: white phosphorus and red phosphorus:



Phosphorus

- White phosphorus:
 - Toxic and waxy, white solid.
 - Low melting point (44 °C).
 - Soluble in nonpolar solvents.
 - Highly reactive in air and must be stored under water.

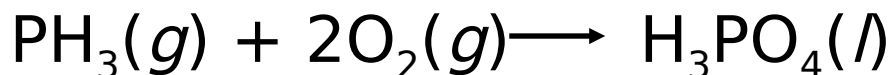


Phosphorus

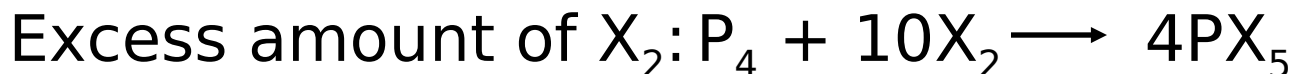
- White phosphorus:
 - Toxic and waxy, white solid.
 - Low melting point (44 °C).
 - Soluble in nonpolar solvents.
 - Highly reactive in air and must be stored under water.
- Red phosphorus:
 - Nontoxic with a polymeric structure.
 - High melting point (579 °C).
 - Less soluble than white phosphorus.
 - It does not ignite on contact with air (less

Phosphorus

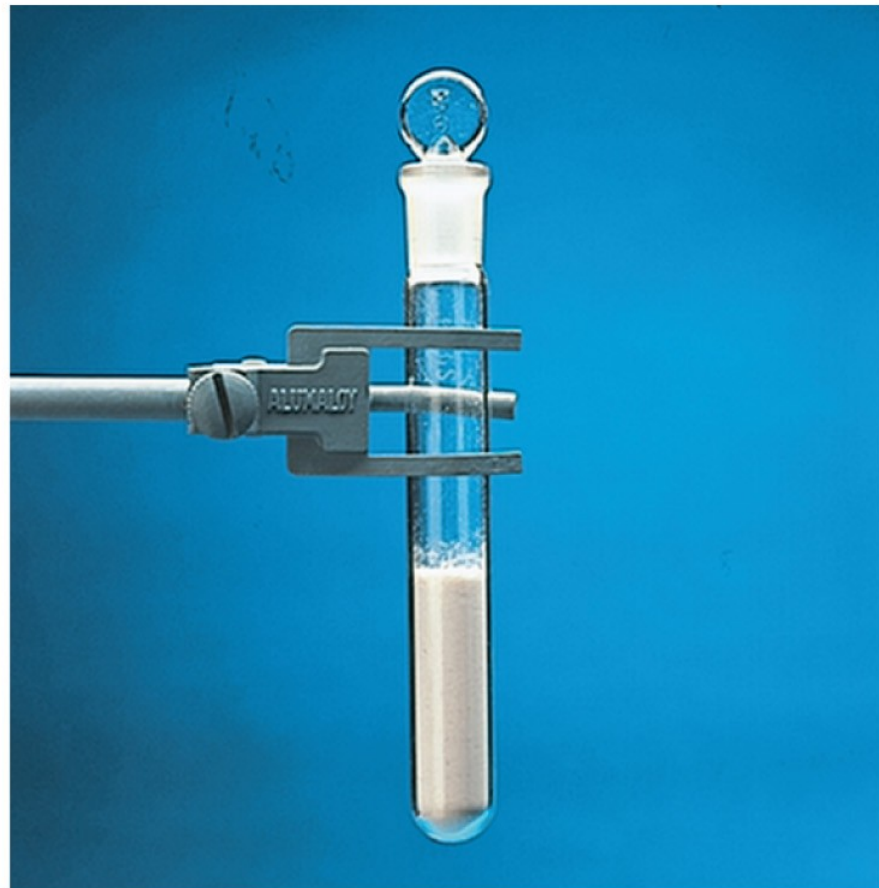
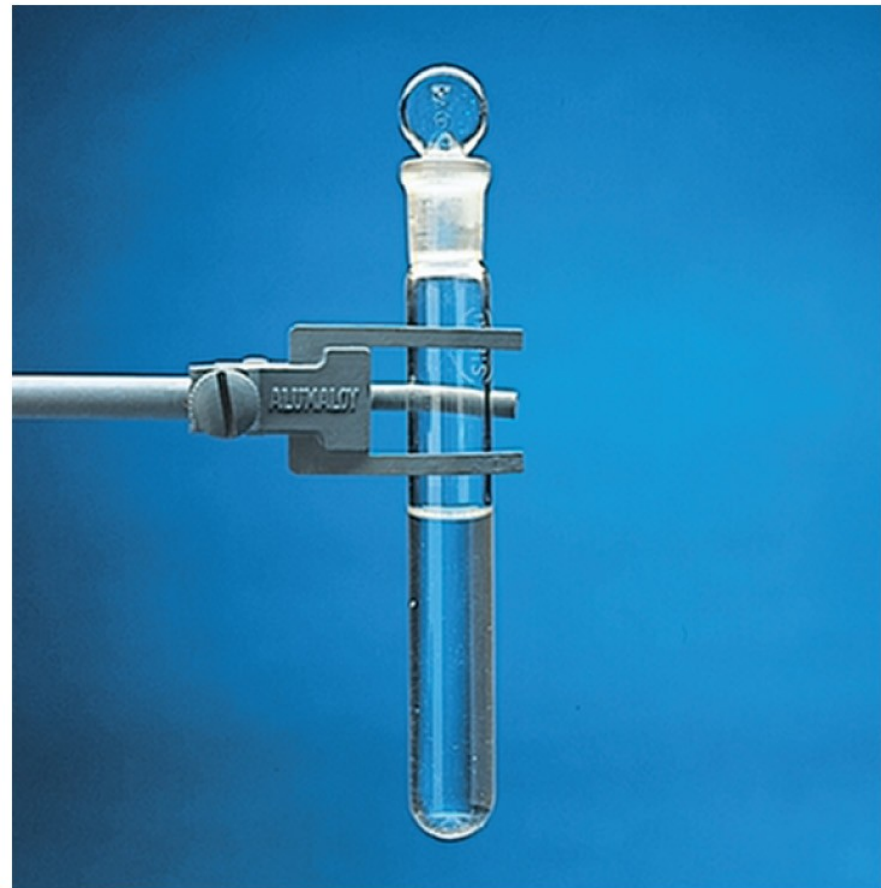
- **Phosphine (PH₃)** is a colorless, extremely poisonous gas. Unlike ammonia, NH₃, its aqueous solutions are neutral. It will burn in air and oxidize to form phosphoric acid:



- **Phosphorus halides (PX₃ or PX₅, X = F, Cl, Br, or I)** are formed by reacting the element with halides:

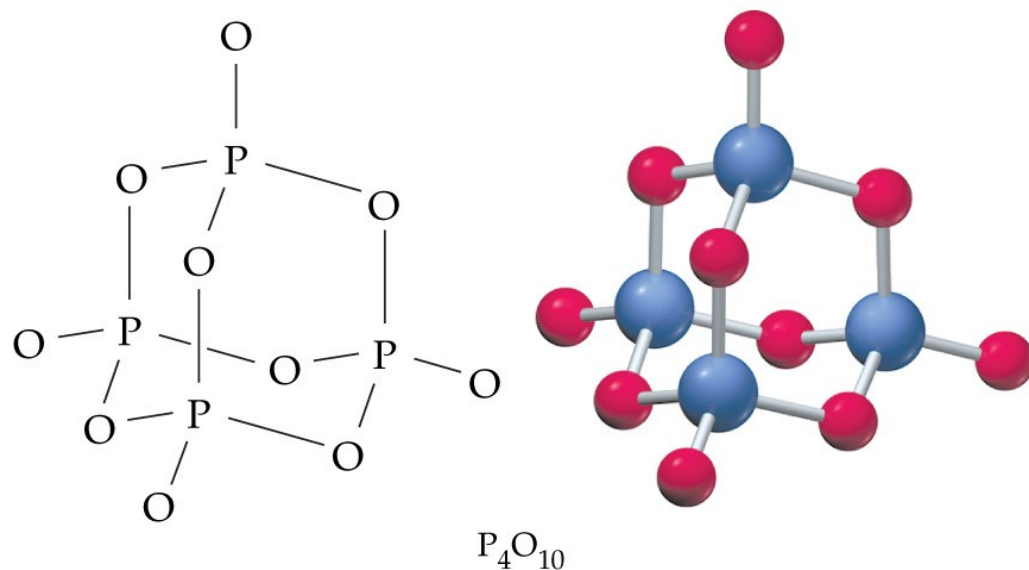
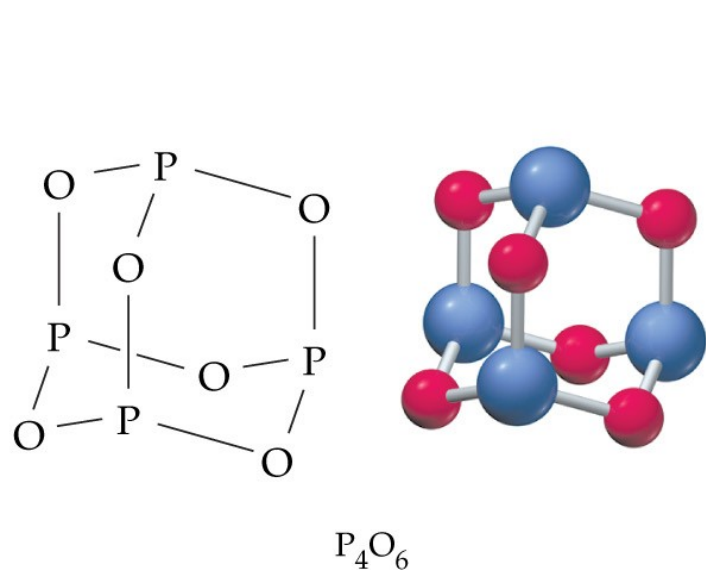
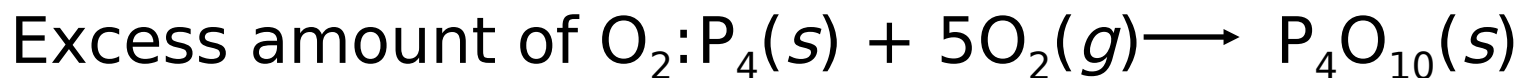
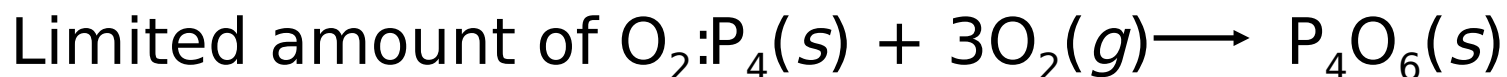


Phosphorus



Phosphorus

- Oxides and oxoacids** are formed when the element is burned in air or oxygen:



Phosphorus



The Group 6A Elements

1A		2		13	14	15	16	17	8A
H	2A			3A	4A	5A	6A	7A	He
Li	Be			B	C	N	O	F	Ne
Na	Mg			Al	Si	P	S	Cl	Ar
K	Ca			Ga	Ge	As	Se	Br	Kr
Rb	Sr			In	Sn	Sb	Te	I	Xe
Cs	Ba			Tl	Pb	Bi	Po	At	Rn
Fr	Ra				114		116		

 = Metals
 = Semimetals
 = Nonmetals

Stairstep line that separates metals from nonmetals

The Group 6A Elements

- Valence electron configuration is ns^2np^4 .
- A common oxidation state is -2. The stability of this state decreases with increasing metallic character.
- Oxygen is a good oxidizing agent but H_2Se and H_2Te are good reducing agents.

The Group 6A Elements

TABLE 19.7 Properties of the Group 6A Elements

Property	Oxygen	Sulfur	Selenium	Tellurium	Polonium
Valence electron configuration	$2s^2 2p^4$	$3s^2 3p^4$	$4s^2 4p^4$	$5s^2 5p^4$	$6s^2 6p^4$
Melting point (°C)	−219	113*	221 [†]	450	254
Boiling point (°C)	−183	445	685	988	962
Atomic radius (pm)	66	104	116	143	167
X ^{2−} ionic radius (pm)	140	184	198	221	
First ionization energy (kJ/mol)	1314	1000	941	869	812
Electron affinity (kJ/mol)	−141	−200	−195	−190	−183
Electronegativity	3.5	2.5	2.4	2.1	2.0
Redox potential, E° (V) for $X + 2H^+ + 2e^- \rightarrow H_2X$	1.23	0.14	−0.40	−0.79	

*Rhombic S

[†]Gray Se

The Group 6A Elements

Selenium



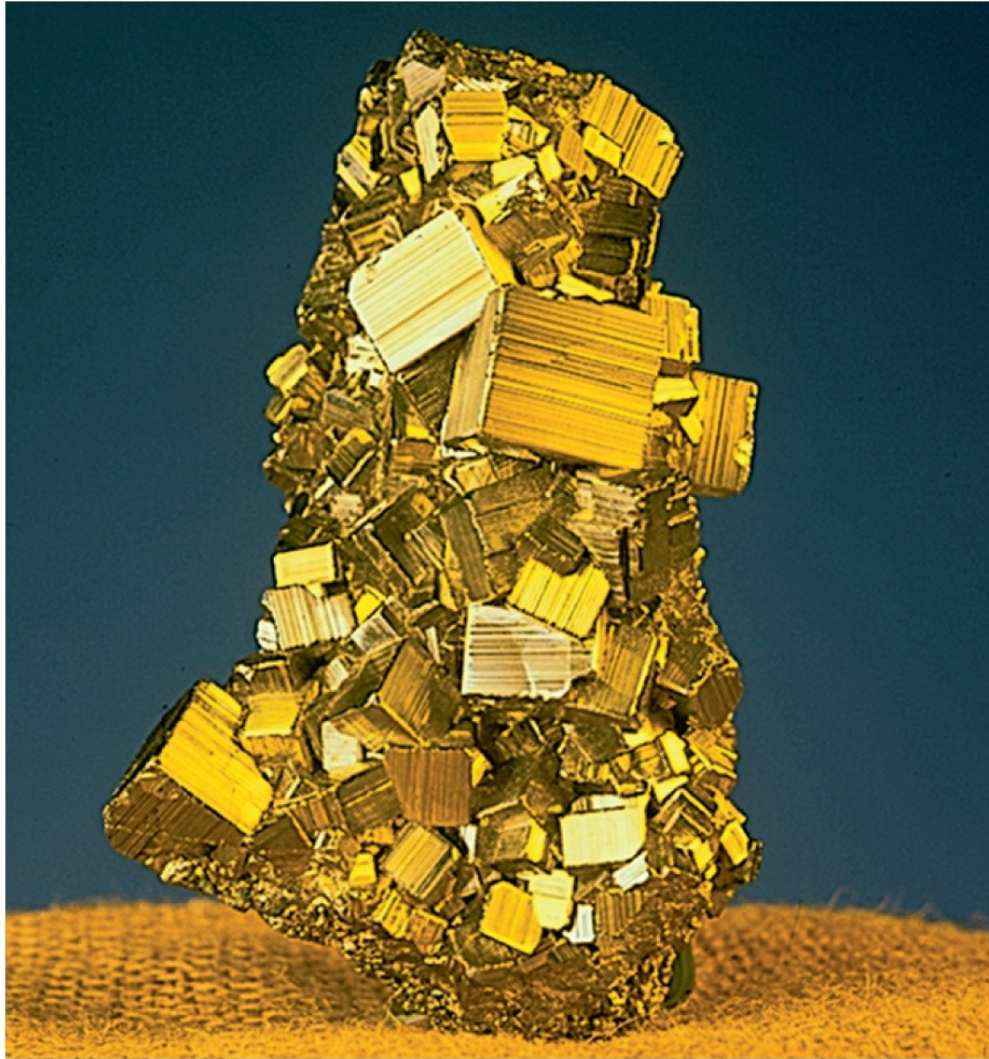
Tellurium



Sulfur

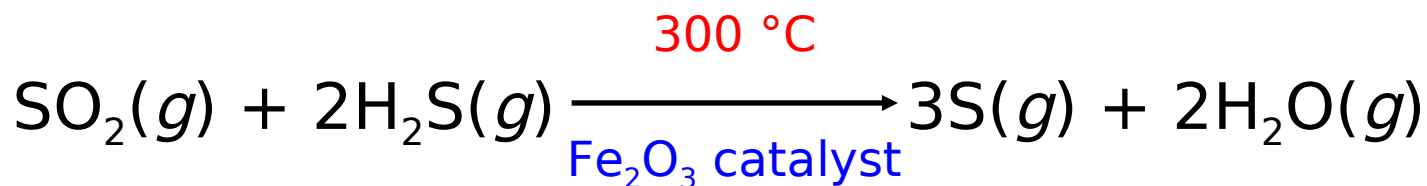
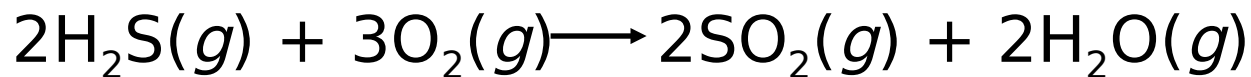
- Sulfur is one of the 10 most abundant elements in the human body.
- It is the sixteenth most abundant element in the Earth's crust and is present in minerals such as pyrite (FeS_2), galena (PbS), cinnabar (HgS), and gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$).
- It is also present in natural gas as H_2S and crude oil as organic sulfur compounds.

Sulfur

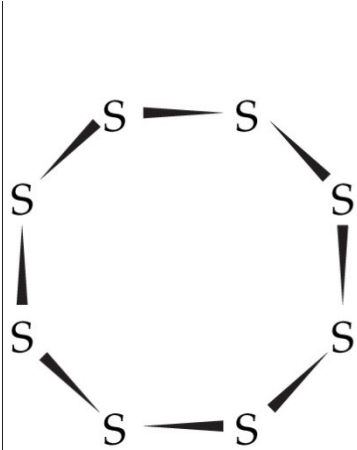


Sulfur

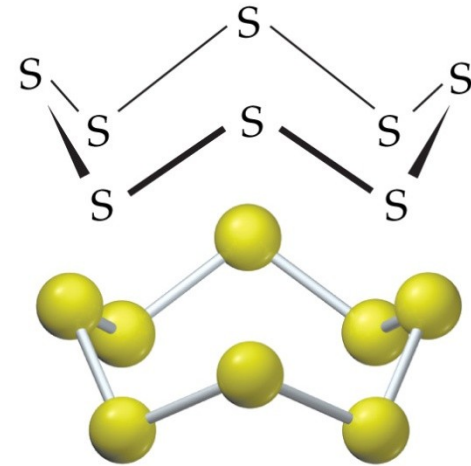
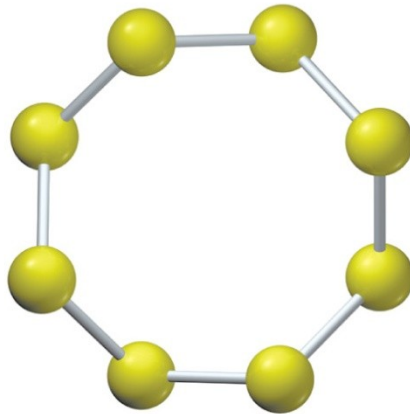
- Elemental sulfur is obtained by recovery from natural gas and crude oil:



Sulfur



Top view



Side view



Sulfur



Fluid, straw-colored liquid sulfur at about 120 °C.



Viscous, reddish brown liquid sulfur at about 180 °C.

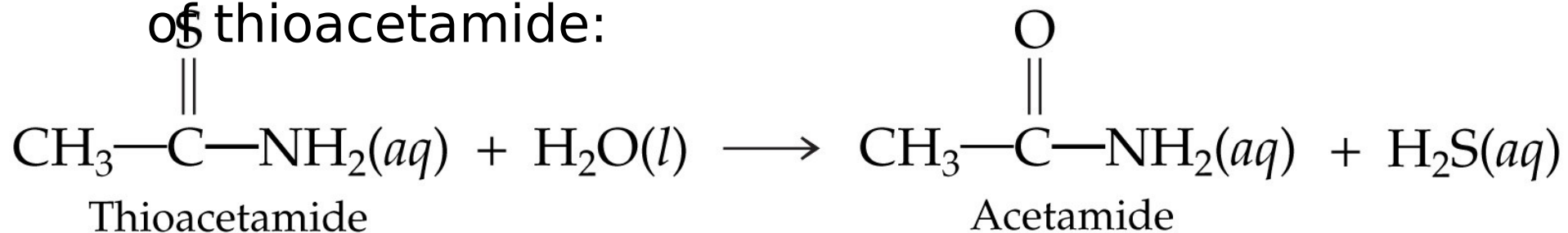


Plastic sulfur, obtained by pouring liquid sulfur into water. Plastic sulfur is unstable and reverts to rhombic sulfur on standing at room temperature.

Sulfur

Hydrogen Sulfide

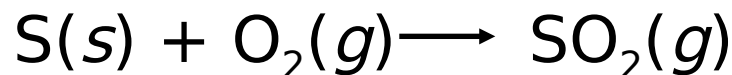
- It is a colorless gas (bp -60 °C) and has a strong odor associated with rotten eggs.
- It is extremely toxic and can cause death at 100 ppm.
- For qualitative analysis in the laboratory, the gas is usually generated in solution by the hydrolysis of thioacetamide:



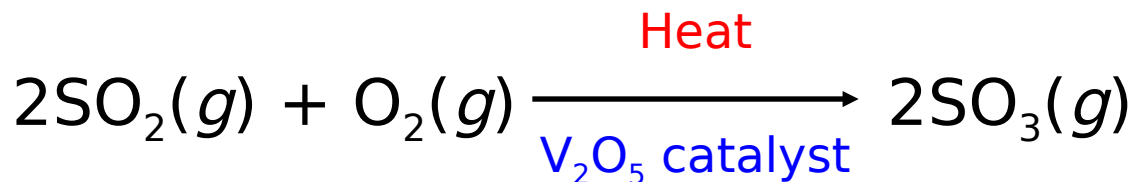
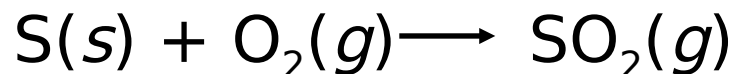
Sulfur

Oxides and Oxoacids of Sulfur

- **Sulfur dioxide (SO₂)** is formed when sulfur burns in air:

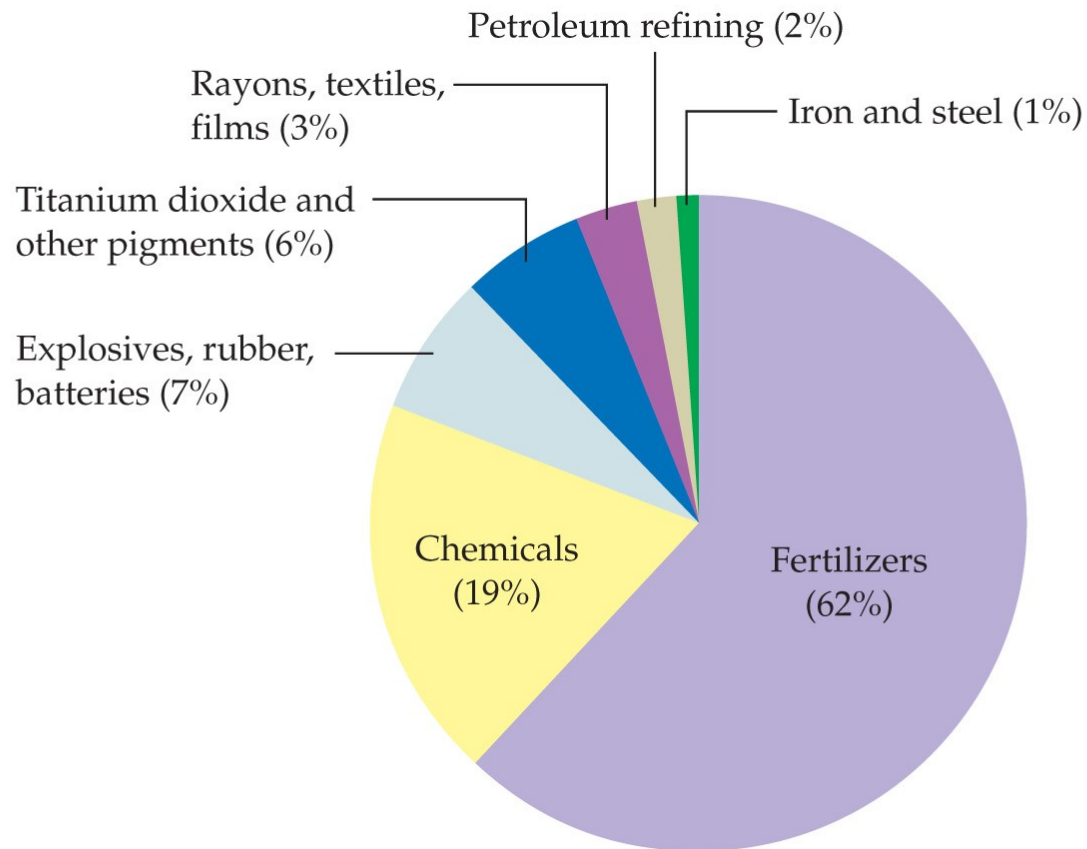


- **Sulfuric acid (H₂SO₄)** is manufactured industrially by the *contact process*:



Sulfur

Uses of Sulfuric Acid



The Halogens: Oxoacids and Oxoacid Salts

1A		2		13	14	15	16	17	8A
H	2A			3A	4A	5A	6A	7A	He
Li	Be			B	C	N	O	F	Ne
Na	Mg			Al	Si	P	S	Cl	Ar
K	Ca			Ga	Ge	As	Se	Br	Kr
Rb	Sr			In	Sn	Sb	Te	I	Xe
Cs	Ba			Tl	Pb	Bi	Po	At	Rn
Fr	Ra				114		116		

Legend:

- = Metals
- = Semimetals
- = Nonmetals

Stairstep line that separates metals from nonmetals

The Halogens: Oxoacids and Oxoacid Salts

- Halogens have a valence electron configuration of ns^2np^5 .
- Acid strength increases with the oxidation state of the halogen.

TABLE 19.8 Oxoacids of the Halogens

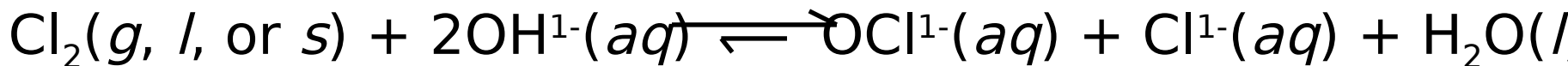
Oxidation State	Generic Name (formula)	Chlorine	Bromine	Iodine
+1	Hypohalous acid (HXO)	HClO	HBrO	HIO
+3	Halous acid (HXO ₂)	HClO ₂	—	—
+5	Halic acid (HXO ₃)	HClO ₃	HBrO ₃	HIO ₃
+7	Perhalic acid (HXO ₄)	HClO ₄	HBrO ₄	HIO ₄ , H ₅ IO ₆

The Halogens: Oxoacids and Oxoacid Salts

- A **hypohalous acid** is formed when Cl_2 , Br_2 , or I_2 dissolves in cold water:

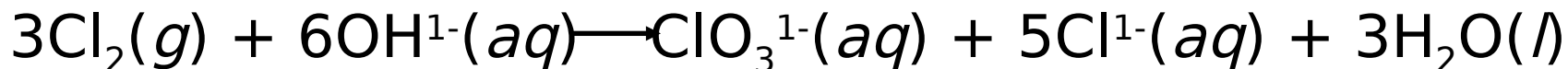


- Bleach (aqueous NaOCl)**, for example, can be made by dissolving chlorine in a basic solution of sodium hydroxide (NaOH):

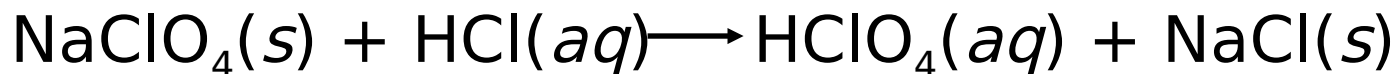


The Halogens: Oxoacids and Oxoacid Salts

- **Chlorate salts** are formed when chlorine, for example, reacts with *hot* aqueous NaOH:



- **Perchloric acid** is produced by reacting sodium perchlorate (NaClO_4) with concentrated HCl:



The Halogens: Oxoacids and Oxoacid Salts

- Iodine differs from the other halogens because it will form more than one perhalic acid:

